Callused Vertigo (*Vertigo arthuri*): A Technical Conservation Assessment

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AUTHOR'S BIOGRAPHY

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Summary of Key Components for Conservation of *Vertigo arthuri*

Status

Vertigo arthuri (callused vertigo) is not considered a federally threatened, endangered, or sensitive species. The Global Heritage status is G2, meaning that the species is considered imperiled (NatureServe 2003). The range of this land snail includes Minnesota, North Dakota, South Dakota, Wyoming, and parts of Canada. In Region 2 of the USDA Forest Service, *V. arthuri* is known only from the Black Hills region of western South Dakota and eastern Wyoming, and it is considered a species of local concern on the Black Hills National Forest. The distribution and taxonomy of this species is not well-understood, so it is possible that the species also exists in other National Forest System lands in Wyoming or Colorado. *Vertigo arthuri* play an integral role within the ecosystem. For instance, they are prey for both invertebrates and vertebrates, thereby serving as an important link in the food chain.

Primary Threats

Vertigo arthuri and other land snails feed on decaying leaf litter and/or the micro-organisms that reside there. Because their habitat needs, certain management activities have the potential to impact snail populations. The primary management threats include fire, roads, recreation activities, timber harvesting, grazing, and mining.

Primary Conservation Elements, Management Implications and Considerations

Because of its limited dispersal ability, patchy distribution, and sensitivity to environmental conditions such as temperature and moisture, populations of *Vertigo arthuri* are subject to extirpation from events that alter or destroy habitat at a particular location. Management activities such as fire, roads, timber harvesting, mining, grazing, and recreation can pose risks under severe conditions. Effects of disturbances may be magnified under recent drought conditions. Recolonization of an area after a disturbance is unlikely for isolated populations. However, if *V. arthuri* is able to self-fertilize like some other *Vertigo* species, then new populations can be founded or re-established from a single individual.

Further information on the life history and distribution of this species is needed before finer scale management decision-making can occur.

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Introduction

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Vertigo arthuri* (callused vertigo) is the focus of an assessment because it was suggested as a species of special concern in the Black Hills National Forest by Frest and Johannes (2002) and is currently considered a species of local concern on that forest. The species was also considered for Region 2 sensitive species status during the Regional Forester's Sensitive Species list revision process in 2001-2003, but it is not currently included on that list (www.fs.fed.us/r2/projects/scp/sensitivespecies). Instead, the evaluation process suggested that it be "considered for other species emphasis lists". Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance or in habitat capability that would reduce its distribution (FSM 2670.5 (19)). A sensitive species may require special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology of *V. arthuri* throughout its range in Region 2. It will facilitate further evaluation of *V. arthuri*, leading to future decisions by the agency regarding the management and conservation status of this species.

This introduction, provided by the Forest Service with minimal modifications by the assessment's author, defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal

Species conservation assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of certain species based on available scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines information needs. The assessment does not seek to develop specific management recommendations. Rather, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, it cites management recommendations proposed elsewhere and, when these have been implemented, the assessment examines their success. Therefore, this assessment does to presume that the species deserves specific conservation status, but it rather provides a summary of information so that management decisions can be made based on this information.

Scope

This assessment examines the biology, ecology, conservation status, and management of *Vertigo arthuri* with specific reference to the geographical and ecological characteristics of Region 2. Although some of the literature on the species originates from field investigations outside the region, this document places that literature in the ecological and social context of the central Rockies. Similarly, this assessment is concerned with behavior, population dynamics, and other characteristics of *V. arthuri* in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

Producing the assessment involved reviewing refereed literature, non-refereed publications, research reports and data accumulated by resource management agencies. Not all publications on *Vertigo arthuri* are referenced in the assessment, nor were all published materials considered equally reliable. The assessment emphasizes refereed literature, where possible, because this is the accepted standard in science. Non-refereed publications or reports were used in the assessment when information was unavailable elsewhere, but these were regarded with greater skepticism. Unpublished data (e.g., Natural Heritage Program records, museum records, etc.) were especially important in estimating the geographic distribution of this species. These data require special attention because of the diversity of persons and methods used in collection. Museum records, while extremely valuable, are most useful when they can all be examined by one qualified individual to confirm species identification; this was beyond the scope of this assessment. The assessment was designed as a summary of existing, readily available information, and therefore does not attempt to revise taxonomy, evaluate museum identifications, or conduct further field surveys for the species.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct experiments that produce clean results in the ecological sciences. Often, observations, inference, good thinking, and models must be relied on to guide our understanding of ecological relations. Confronting uncertainty then is not prescriptive. Experiments addressing the effects of many management activities on mollusks are not available, so these alternative approaches are utilized. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate.

In cases where articles or reports make statements without supplying the supporting data, the lack of support for the authors' statements is indicated. Discussions of uncertainty of particular references described in this report are not meant as indictments of individual scientists or their work. Rather, this report points out situations where particular data or support are not available from the written documents. In some cases, the scientists may be continuing the work, and the information may become available in the future.

Uncertainty also comes into play when life cycle models are discussed. Due to a lack of basic biological information on this species, developing an accurate population model is extremely difficult. Since the basic demographic parameters are unknown, mathematic simulations are not particularly useful because the error becomes larger than potential effects found.

Application and Interpretation Limits of this Assessment

Information used to complete this assessment includes studies from across the geographical range of the species. Although it would be desirable to have information on life history and ecology specific to Region 2, in most cases that is not available for this species. Most information should apply broadly throughout the range of the species, but certain life history parameters may vary along environmental gradients. Inferences made from this information regarding threats to the species are understood to be limited in scope (see section above) and take into account the particular conditions present in Region 2. Therefore, information regarding conservation status of this species pertains specifically to Region 2 and does not necessarily apply to other portions of the species' range.

Publication of Assessment on the World Wide Web

To facilitate their use, species assessments are being published on the Region 2 World Wide Web site (www.fs.fed.us/r2/projects/scp/assessments). Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. In addition, Web-based publications can be easily revised; revision will be accomplished based on guidelines established by Region 2.

Peer Review

Assessments developed for the Species Conservation Project have been peer reviewed prior to their release on the Web. This report was reviewed through a process administered by The Society for Conservation Biology, an independent scientific organization, which chose two recognized experts to provide critical input on the manuscript. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

Management Status and Natural History

Management Status

Vertigo arthuri is not included on the federal list of endangered or threatened species in the United States (U.S. Fish and Wildlife Service 2003). The Global Heritage status is G2, meaning that the species is considered imperiled (NatureServe 2003). In South Dakota, the species is listed as an S2 species (a species vulnerable to extinction), but the status in other states within its range (Minnesota, North Dakota, and Wyoming) is unknown (NatureServe 2003). *Vertigo arthuri* is not included on the USFS Region 2 Sensitive Species list. Although Robert Forsyth, of the Royal British Columbia Museum, reports *V. arthuri* from British Columbia, the species does not currently have any official status in Canada. This is most likely because Forsyth's findings have not yet been published

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Within USFS Region 2, only the Black Hills National Forest addresses management of this species. The management guidelines state the goal is to "ensure that all identified colonies of …*Vertigo arthuri*…are protected from adverse effects of livestock use and other management activities" (U.S. Forest Service 1997).

While the overall goal is adequate to protect this species, more specific guidelines are needed for managers to understand what specific activities may adversely affect this species and what steps might be useful to mitigate those impacts. A better understanding of the distribution and ecology of this species is probably needed (see Information Needs section) before mitigation measures can be designed specifically for *Vertigo arthuri*. However, guidelines with specific standards for management activities in known snail habitats and directives promoting healthy land snail communities in general could be designed at the forest level.

Biology and Ecology

Systematics and general species description

Vertigo species are pulmonate terrestrial gastropods (i.e., land snails with lungs) belonging to Phylum Mollusca: Class Gastropoda: Order Stylommatophora: Family Pupillidae. At least 37 species of *Vertigo* are present in North America (Turgeon et al. 1998). Turgeon et al. (1998) consider the classification of *V. arthuri* uncertain, probably because at the time of that publication only one location was published in the literature.

Vertigo arthuri, originally recognized by von Martens in 1882, is described by Pilsbry (1948) as having a small (1.68 mm by 0.95 mm [0.066 by 0.037 inches]) conically shaped shell with 4.75 whorls. The distinguishing characteristic of *V. arthuri*, like most *Vertigo* species, is the structure of the teeth within the aperture opening (see definitions at the end of the report for descriptions of morphological terms). Pilsbry described the teeth as follows: "…a small, tubercular angular lamella near the rather large and long parietal lamella. Columellar lamella is stout, a convex callus against its lower side. The outer lip is very heavily calloused a short distance within; a short upper-palatal fold and a long and deeply entering lower-palatal run inward from the callus. The basal fold is quite small, near the base of the columella"(pages 977-978). A drawing of *V. arthuri* is shown in **Figure 1**.

Distribution and abundance

Pilsbry (1948) was only aware of one known location of this species, near the Little Missouri River in North Dakota. More recent surveys have shown additional locations, expanding the range to include South Dakota, Wyoming, and Minnesota (NatureServe 2003). **Figure 2** shows the distribution of *Vertigo arthuri* in the United States. Nekola (2002a) also mentions sites near Edmonton, Alberta, Canada. Robert Forsyth, of the Royal British Columbia Museum, also reports *V. arthuri* from British Columbia (personal communication 2003). Wayne Grimm, of the Eastern Ontario Biodiversity Museum, has found *V. arthuri* at various locations across Canada, including in the Yukon (personal communication 2003).

No information on the historical distribution of this species is available. Frest and Johannes (2002) speculate that the species was much more widespread in the Black Hills when riparian forests were more intact.

In Region 2, the only known locations are in the Black Hills of South Dakota and Wyoming (**Figure 3**). The species is found in the Black Hills National Forest (Frest and Johannes 2002) and in the adjacent Wind Cave National Park (Anderson 2003). Future surveys may uncover additional locations in the region, although other published literature fails to mention the species in the region (Henderson 1924, Beetle 1976, Beetle 1989, Jass et al. 2002).

The Black Hills surveys include both living specimens and shells as evidence of current distribution. Frest and Johannes (2002) report 63 locations in the Black Hills National Forest with such evidence. Anderson (2003) reports two locations in Wind Cave National Park with an average of four snails/shells per site. Frest and Johannes (2002) do not provide any quantitative information on abundance, but they do state "it was never abundant" (page 64). Nekola (2002a) reports *Vertigo arthuri* from 73 locations across 14 counties of northwestern Minnesota, with averages ranging from 0.12 to 14.14 individuals per site across several different habitat types. Unfortunately, none of these studies were designed to address the question of abundance per unit area, so "typical" abundances are unknown.

Limited data on density are available for other *Vertigo* species. Prokryszko (1990) provides density information for *V. pusilla* in Poland. In the studied population, densities varied across the seasons from 100 individuals per m^2 to 900 individuals per m^2 (100 to 900 snails per 10 square feet). *Vertigo moulinsiana*, a species that inhabits wetland vegetation, varied from less than 50 individuals per m^2 to 600 individuals per m^2 (50 to 600 snails per 10 square feet) at one location in England (Killeen 2003).

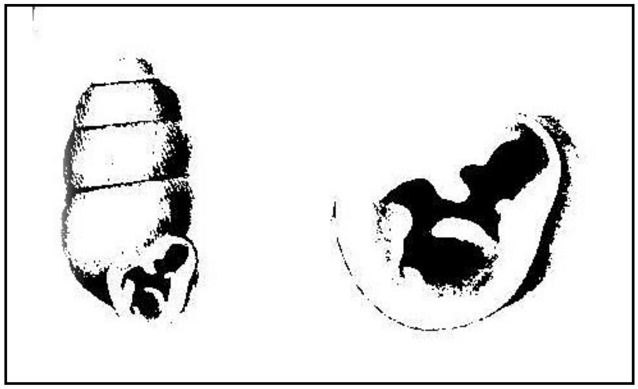


Figure 1. Drawing of *Vertigo arthuri*. From Pilsbry (1948). Used with permission.

Known Distribution of *Vertigo arthuri*

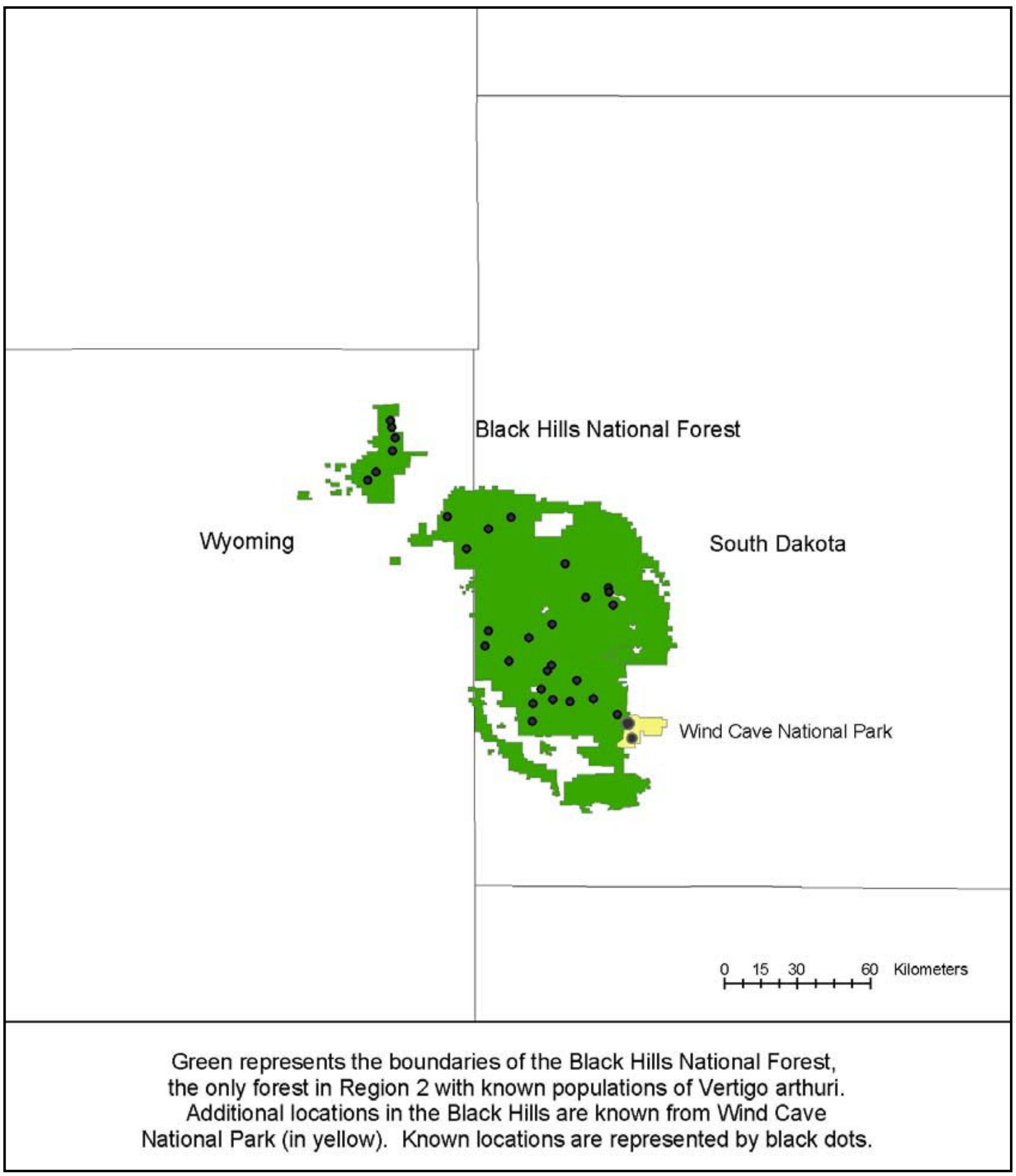
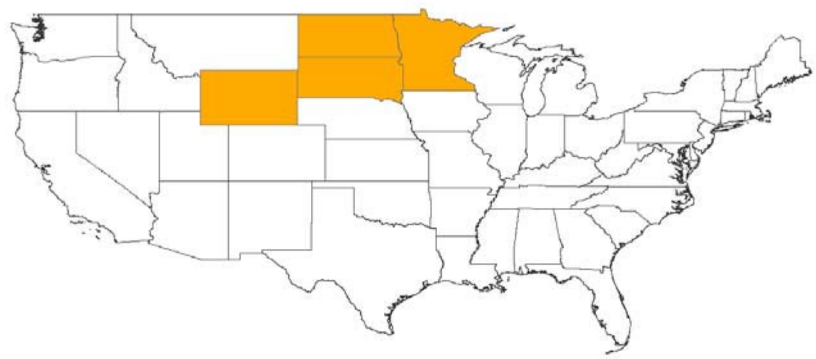


Figure 2. Map of known distribution of *Vertigo arthuri* in Region 2.

Known U.S. Distribution of *Vertigo arthuri*



States with reported records of *Vertigo arthuri* are shown in orange. Additional locations have been reported in Canada, but these are not shown on this map.

Figure 3. Entire known range of *Vertigo arthuri*.

Vertigo arthuri are restricted to suitable habitat and are even patchily distributed within the habitat. Populations that are only a kilometer apart may be considered isolated if individuals are not able to disperse between them. Information on dispersal of *V. arthuri* is not available, but see the Demography section below for a discussion of snail dispersal in general.

Population trend

No information is available to evaluate population trends for *Vertigo arthuri* either nationally or in Region 2. No population estimates are available for any locations, and no density estimates are recorded for sites with repeat visits.

Temporal patterns of abundance are most likely constant at the regional level. Without human intervention or rare passive dispersal events, snails are not subject to spontaneous outbreaks in locations where they are not previously recorded. At the local level, snail populations fluctuate based on weather and time of year. For example, *Discus macclintocki* populations in Iowa fluctuate with moisture levels (Henry et al. 2003). In addition to actual population size fluctuations, activity levels vary with temperature or time of year, so snails may be more noticeable at certain times, when they may be active at the surface rather than when they are aestivating.

Activity pattern and movements

Land snails aestivate when conditions are not favorable, remaining in their shell until conditions improve. They may take refuge under litter or rocks or deeper in the soil. Activity levels for snails vary with temperature, moisture, and/or time of year.

The amount of dispersal is highly variable among snail species. Larger species generally move longer distances than smaller species. For example, *Achatina fulica* (giant African snail), which weighs about 30 g (1.06 ounces), moved up to 500 m (0.31 miles) in six months when released in a study in the Bonin Islands in the Pacific (Tomiyama and Nakane 1993). *Theba pisana*, which measure 1.5 cm (0.59 inches) (Abbott 1989), dispersed up to 300 cm (118 inches) over 100 days in a European study (Cowie 1984). Some species are apparently more sedentary, perhaps because of the patchiness of their habitat. For example, studies in

Iowa of *Discus macclintocki*, which measure 5 mm (0.2 inches), found individuals rarely moved even 2 m (6.56 feet) (Anderson 2000, Henry et al. 2003). Adult *Albinaria corrugata*, which reside on boulders in the Swiss Alps, moved less than 2 m (6.56 feet) over a one-year period 90 percent of the time (Schilthuizen and Lombaerts 1994). Evidence that juveniles disperse farther than adults was found for *Achatina fulica* (Tomiyama and Nakane 1993), but not for *Theba pisana* (Cowie 1984) or *Albinaria corrugata* (Schilthuizen and Lombaerts 1994). Dispersal may also vary with the season, as in *Arianta arbustorum* in the Swiss Alps, which averaged 2.6 m (8.5 feet) per month in June and 1.1 m (3.6 feet) per month in August (Baur 1986). No information is available for dispersal distances or age differences in dispersal patters for *Vertigo arthuri* or any other species in the genus.

Snails are also subject to passive dispersal. Snails (*Arianta* spp.) in the Swiss Alps rolled downhill due to gravity, were pushed by avalanches, or were swept away by heavy rains and streams (Baur 1986, Baur et al. 1997). Other studies indicate that streams are major paths for gene flow in snails (Arter 1990, Ross 1999). *Vertigo moulinsiana* displayed a pattern of colonizing a series of pools in England that is consistent with the idea of dispersal by water (Killeen 2003). Movements by avalanches or snowmelt events and stream flow could be a factor in moving *V. arthuri* among habitats within the same watershed in the Black Hills.

Long-range passive dispersal of snails is likely accomplished with the help of wind and birds (Rees 1965). However, this has not been observed in *Vertigo arthuri*, and if it occurs, it is probably a rare event. Therefore, *V. arthuri* in the Black Hills are completely isolated from populations in other locations (i.e., Minnesota and North Dakota). Populations within the Black Hills on different drainages may also be isolated if they are separated by inhospitable habitats, unless human activity happens to move the snails between locations. Again, specific information on movement of *V. arthuri* is not available.

Habitat

Vertigo arthuri have not been studied extensively enough to distinguish between habitats used versus those selected, preferred, or required. Also, information is not available on a small enough scale to determine if there are differences between microhabitats needed for foraging versus brooding of young. Therefore, in this section, "habitat" will refer only to where *V. arthuri* are found.

Nekola (2002a) found *Vertigo arthuri* in 12 different habitat types in northwestern Minnesota: balsam-white spruce forest, white cedar wetland, aspen forest, black ash wetland, maple-basswood forest, jack pine forest, red pine forest, oak forest, sedge meadow, tamarack wetland, wet prairie, and fen habitats. *Vertigo arthuri* were significantly more likely to occur in forest habitat than grassland habitat, and the highest densities occurred in balsam-white spruce forest and aspen forest. Nekola (2002a) also mentions that known Alberta sites are within the Aspen Parkland, suggesting aspen may be an important habitat for this species.

In the Black Hills, the species is a bit more restricted in its current habitat. Frest and Johannes (2002) describe the habitat as dominated by *Picea glauca* (white spruce) or *Pinus ponderosa* (ponderosa pine) with various understory vegetation including *Cornus canadensis* (bunchberry), *Aconitum* spp. (monkshood), *Maianthemum canadensis* (wild lily-of-the-valley), *Viola canadensis* (Canada violet), *Aralias* spp. (wild sarsaparilla), and *Pyrola* spp. (shinleaf). They also characterize the locations as "wet, relatively undisturbed forest" having "deep litter, generally on shaded north-facing slopes, often at the slope base or extending slightly onto the adjacent floodplain" (page 64). Anderson (2003) found *Vertigo arthuri* at both bur oak (*Quercus marcrocarpa*) riparian and mountain mahogany (*Cercocarpus montanus*) shrubland locations. A photograph of a mountain mahogany area where *V. arthuri* is found is shown in **Figure 4**.

Soil type also plays a role in determining appropriate snail habitat. Frest and Johannes (2002) state that this species was usually found on limestone substrate and occasionally on schist soils. These types of soils are found in many areas of the Black Hills (Froiland 1990).

Pilsbry (1948) describes the habitat for North American *Vertigo* species, in general, as follows: "They are generally to be found on and under dead wood and fallen leaves in humid places, but also some species live on grass stems and dead leaves at the borders of ponds or marshes. In the mountain states they are partial to aspen groves" (page 943). Different amounts of ground cover are apparently preferred by different species. In the upper Midwest, snails were categorized as preferring duff (thicker organic layer), turf (organic layer of less than 4 cm), or generalists (Nekola 2002b), with *Vertigo* species represented in each category. *Vertigo arthuri* was not classified because of insufficient sample sizes.

Figure 4. Habitat where *Vertigo arthuri* was found in the Black Hills includes shrubland habitat such as the mountain mahogany shown here. Photo by T. Anderson.

Food habits

Herbivorous snails eat by scraping their radula along food surfaces (see general works on invertebrates, such as Pearse et al. 1987, for more information). The only available information on feeding habits of *Vertigo arthuri* is a statement written by Frest and Johannes (2002) that it "appears to feed on the surfaces of half-decayed leaves" (page 64). The reported observations of this feeding behavior do not distinguish whether the snails are actually eating the leaves themselves or fungi or microorganisms growing on the leaves. It is unknown whether *V. arthuri* prefer decaying leaves (or fungi) of a particular species. No information is available on whether feeding habits are different between juvenile and mature *V. arthuri*.

Breeding biology

No specific information on the breeding biology of *Vertigo arthuri* is available. *Vertigo* species are hermaphrodites based on the anatomy described by Pilsbry (1948). Information on European *Vertigo* species illustrates potential species differences, making extrapolations from one species to another difficult. *Vertigo pusilla* are reported to lay eggs in spring (Prokryszko 1992, as cited in Drake 1999). *Vertigo angustior* in Great Britain lay eggs in the fall (Fowles

1998). Deducing from the presence of immature snails, *V. moulinsiana* gave birth in October in the Netherlands (Butot and Neuteboom 1958, as cited in Drake 1999), January in Ireland (Philips 1908, as cited in Drake 1999), and anytime between September and December in England (Stebbings and Killeen 1998). Studies of *V. pusilla* in Europe showed that the species lays one to two eggs at a time and are reproductively mature in one month (Pokryszko 1990). It is not clear whether adults were reproducing multiple times.

Several other *Vertigo* species studied in Europe (*V. arthuri* was not among those studied) have both aphallic and euphallic individuals (Pokryszko 1987, 1990). The aphallic individuals with reduced male reproductive organs are apparently able to either serve as females when cross-fertilization occurs, or can self-fertilize. Self-fertilization was commonly observed in *V. pusilla* (Pokryszko 1990), but it is unknown if this occurs in *V. arthuri*.

It should be noted that different *Vertigo* species reside in different habitats ranging from marshes to dry grasslands to forests, so the local habitat may influence the amount of time during which conditions are acceptable for breeding. Therefore, species with different habitat preferences may also have different breeding habits.

Demography

Population dynamics are determined by rates of survival and reproduction, life history characteristics, and movement in and out of the population. If specific data can be gathered on the demography of the species, then management and monitoring are much easier. Unfortunately, most of this information is not available for mollusk species. In addition, the small size and patchy nature of many mollusk populations create other concerns.

Genetic characteristics and concerns

Small isolated populations of animals are subject to inbreeding, which can lead to decreased genetic diversity and possibly reduced fitness and even extinction in the long run (Saccheri et al. 1998). Snail colonies are likely to be somewhat isolated from one another, so inbreeding could become an issue. On the other hand, isolated colonies may be the norm for this species, which might indicate that they are not affected by lowered genetic diversity. A study of the genetic diversity within *Vertigo arthuri* is not available, so it is unknown how much diversity exists within the species.

Hybridization

It is unknown if *Vertigo arthuri* hybridizes with any other species. Several other *Vertigo* species reside in the region, and more information of the taxonomic relationship among these species might shed light on this issue.

Life history characteristics

No information is available on recruitment, survival, immigration, or emigration rates for *Vertigo arthuri*. Age of first reproduction is unknown. The proportion of the population that is breeding and the characteristics of non-breeders are unknown. No life history studies have been published for any North American *Vertigo* species. The European *V. pusilla*, which resides in dry habitats, lives 1 to 1.5 years in the laboratory (Pokryszko 1990). Monitoring data (one visit each month for three months) of relocated *V. moulinsiana*, a marsh species in England, could not distinguish between rapid maturity rates or high juvenile mortality rates (Stebbings and Killeen 1998).

A life cycle diagram is shown in **Figure 5**. This diagram is tentative because several aspects of the life history of *Vertigo arthuri* are unknown. The life cycle is stage-based (Caswell 2001) because maturity is not necessarily a standard time frame and may vary with environmental conditions. The three stages of the life-cycle shown are: 1) sub-adult or juvenile stage, 2) mature, reproductive adult stage, and 3) post-first reproduction adults. In the diagram, variables are shown for the probability of successfully reaching each stage from the stage before (P), fertility (F), and the productivity of an individual (m). The probability of juveniles (stage 1) surviving and successfully maturing to adulthood (stage 2) is given as P_{21}. Probabilities (P) of reaching each successive stage are listed in a similar fashion. The fertility (F) or number of juveniles produced is a function of both the number of eggs produced by an adult (m) and the probability of an individual reaching the adult stage (P_{21}). Should numerical data become available in the future for survival and productivity of *V. arthuri* at these stages, this diagram could be used to construct a demographic model (after McDonald and Caswell 1993, Caswell 2001).

A demographic matrix (Caswell 2001) is not provided because of the many unknown factors in the life cycle. For example, do adults breed more than once? Caswell (2001, pages 60-62) provides an example of an incorrect life cycle diagram for a plant species where an extra stage in the life cycle diagram produced a growth

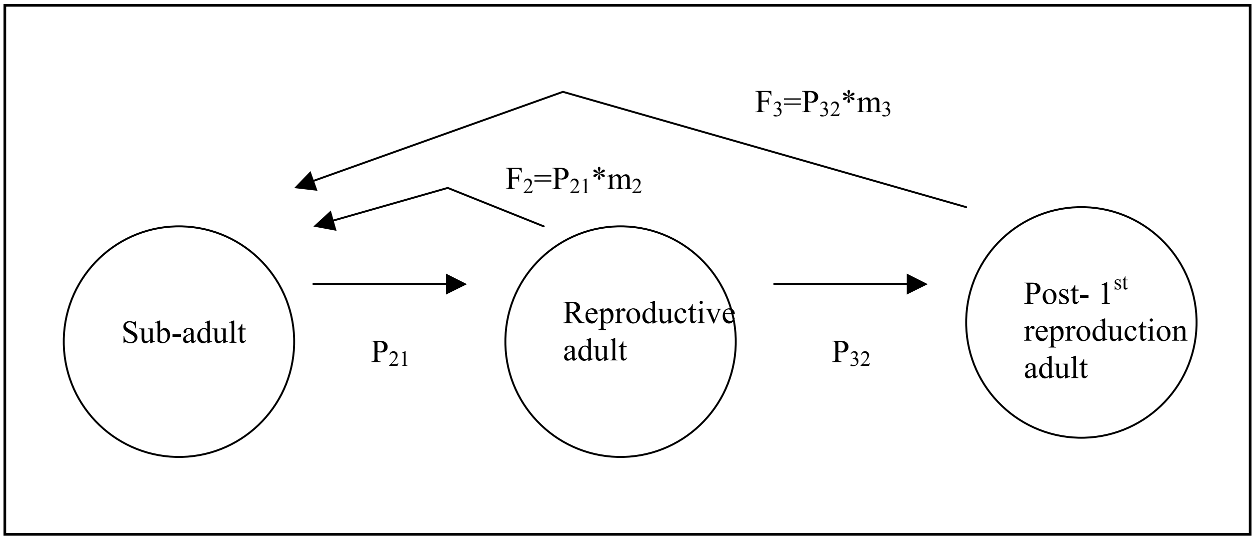


Figure 5. Life cycle diagram for *Vertigo arthuri*. See text for further information.

rate estimate of 1.8, when the correct diagram estimates lambda equals 2.4. In addition, no life tables are available for this species from which to obtain values for survival rates. Life table information is not available for any other North American *Vertigo* species either. Some authors assign values for missing stages to obtain a stable growth rate of 1. However, there are so many missing values in this model, that this is not possible. In addition, the stable growth rate assumption may not be valid for snails because their populations can be somewhat cyclical. No Population Viability Analysis models are available for this species either.

Ecological influences on survival and reproduction

Snails are heavily influenced by environmental conditions. They aestivate in unfavorable conditions, which can extend the time to maturity and/or the time between breeding periods.

Social spacing

No information is available on whether *Vertigo arthuri* has territories or what the home range of an individual snail might be.

Patterns of dispersal

No information is available on *Vertigo arthuri* dispersal patterns. A general discussion of snail dispersal is found above in the Activity pattern and movement section.

Spatial characteristics

Populations of *Vertigo arthuri* in the Black Hills are usually separated by several kilometers (**Figure 3**). The degree to which these populations are isolated depends on their dispersal patterns, which are largely unknown.

Factors limiting population growth

Studies that directly address limits to population growth are not available. However, it is likely that populations are generally limited by changes to their habitat that affect the temperature, moisture level, amount of shelter, or type of food available. Increased temperature and/or decreased moisture in the habitat will increase the amount of desiccation in the snails. Decreased litter layers or changes in vegetation components of litter may decrease the amount of shelter that snails have available, not only from predators, but also from desiccation. Changes in the type and/or structure of vegetation in an area will affect not only the temperature and moisture, but also the amount of litter and food available.

Community ecology

Very little has been published about the community ecology of any *Vertigo* species, much less anything specific to *V. arthuri*.

Predators

Snails are prey for some birds (Ehrlich et al. 1988) and rodents. Other invertebrates may also prey on snails. Which vertebrate or invertebrate species in the region utilize *Vertigo arthuri* and how much pressure predation puts on the snail population are unknown.

Competitors

Presumably other snail species and other small herbivorous invertebrates may compete with *Vertigo arthuri* for food. In the Black Hills, *V. arthuri* co-occurs with many other land snails, including other *Vertigo* species (Frest and Johannes 2002, Anderson 2003). There is no evidence that competition is limiting the species' range.

Parasites and disease

Vertigo species are known to be secondary hosts for parasites such as lungworms (*Protostrongylus* spp.) that infect sheep and rabbits in the region (Thorne et al. 1982). The mortality rate of *V. arthuri* due to parasite infection is unknown.

Symbiotic and mutualistic interactions

Symbiotic and mutualistic interactions with *Vertigo arthuri* are unknown.

Envirogram

An envirogram showing the hypothesized important relationships for *Vertigo arthuri* is shown in **Figure 6**. Envirograms (after Andrewartha and Birch 1984) are graphical representations of the 'ecological web' of complex pathways that influence an animal's survival. The center (centrum) of the web is the focal animal, in this case *V. arthuri*. Each step out from the center is influenced by the factors in other steps of the web. For example, factors listed in level 2 of the web affect those factors in level 1 of the web and are themselves affected by the factors in level 3 of the web. Both positive (resources) and negative (malentities) influences are shown on the envirogram. In this case, food, cover, calcium, and moisture are essential for the snails to survive. Predation, desiccation, and habitat loss are shown as having negative impacts on *V. arthuri*.

CONSERVATION

Threats

Snails face many potential threats to their survival. The disturbances that occur in Region 2 are treated individually below. The effects of management activities on *Vertigo arthuri* have not been directly tested, so information from other snail species is summarized below and the relationships to *V. arthuri* are discussed. Management activities can affect snail populations directly or indirectly, and both types of effects are discussed. The discussion of the management activities below focuses on how these activities may potentially impact snails and their habitat. This discussion is not meant to imply that these activities necessarily pose a dire threat to the species as a whole. Rather, the information is presented so that activities can be evaluated on a case by case basis at the local level.

Fire

Although fire is a natural disturbance with which *Vertigo arthuri* has presumably evolved, there are still potential concerns regarding how the species may recover from natural and prescribed fire events. As a species with minimal dispersal abilities, individuals may not be able to move to other suitable areas after a fire. Any additional barriers to dispersal (i.e., roads) or loss of habitat further complicate recovery of populations.

Fire (wild or prescribed) can potentially eliminate essential habitat for snails. Some known populations of *Vertigo arthuri* are located within areas that have been burned in wildfires over the last few years (**Figure 7**). No live snails of any species were found at five locations within the perimeter of a burn that occurred in 2000. The fire resulted in a typical mosaic with more and less severely burned areas, and it is unclear how severe the fire was at these specific sites. The sites, not all *V. arthuri* sites, were re-surveyed by USFS personnel in 2001 or 2002 (Burns personal communication 2003). However, the sites were not visited multiple times, so more information is needed to conclusively say that snails are no longer present. The long-term effect of the fires on populations of *V. arthuri* has yet to be determined because the species' ability to re-colonize is largely unknown. It is also unknown whether the species is able to survive low-intensity fire events (i.e., fires where only small amounts of available fuel are consumed).

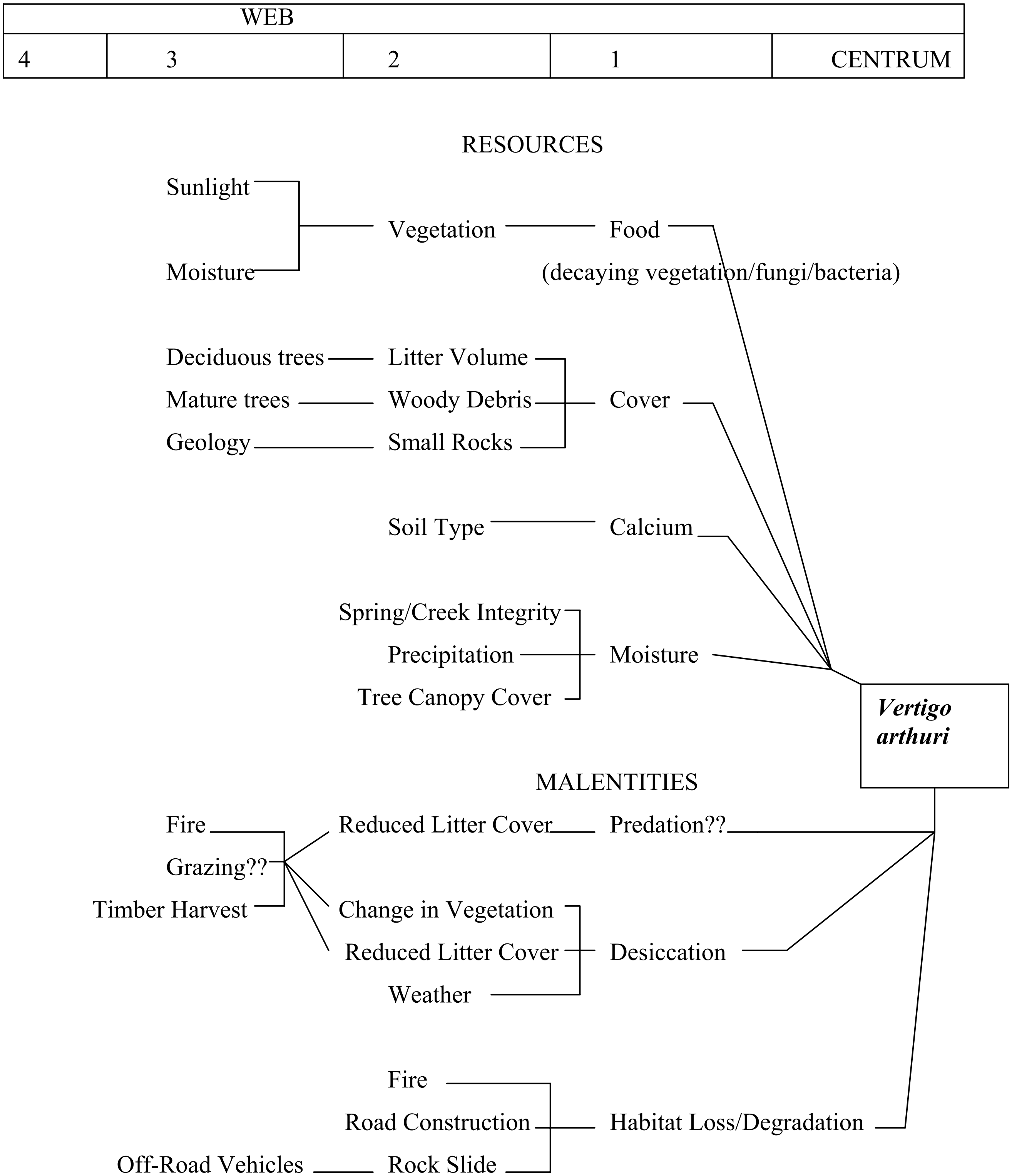


Figure 6. Envirogram for *Vertigo arthuri*.

Recent Fire Activity in Relation to Known Populations of *Vertigo arthuri*

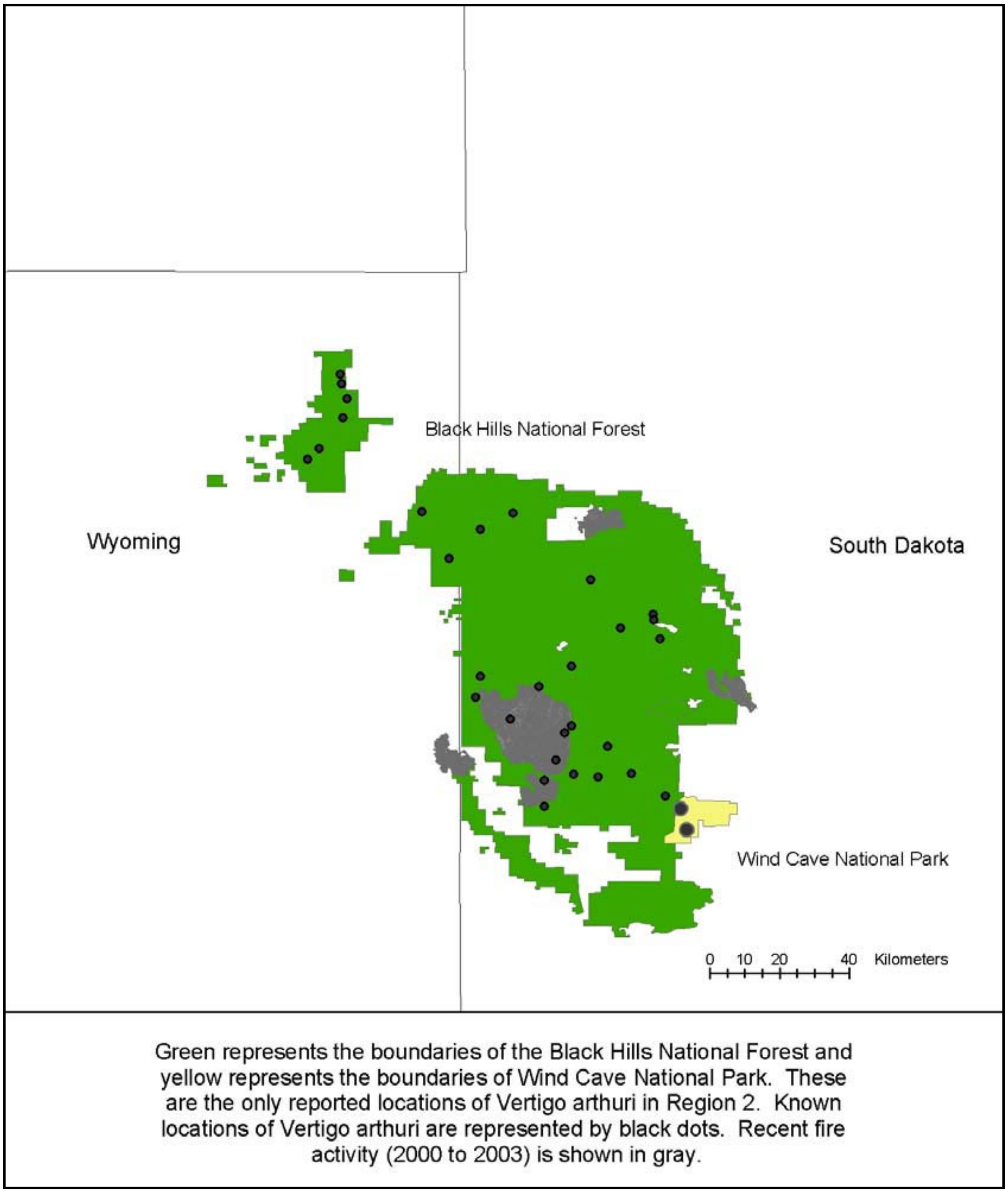


Figure 7. Recent fire activity to known populations of *Vertigo arthuri*.

Nekola (2002b) did not detect *Vertigo arthuri* in burned habitats in northwestern Minnesota. However, a statistically significant difference in the abundance of *V. arthuri* between burned and unburned habitats could not be detected, presumably because the species occurred in very low densities (average abundance in unburned areas was 0.643). Three other *Vertigo* species (*V. elatior*, *V. morsei*, and *V. milium*) had significant negative responses to burned areas, while one *Vertigo* species (*V. pygmaea*) responded positively. The burn severity was not reported in this study.

No other information regarding the effects of fire is available for *Vertigo arthuri* specifically. What follows is a summary of information drawn from studies on other species. Little information is available about the effects of fire on snails, and the available data give conflicting conclusions.

Strayer et al. (1986) studied forest sites in Maine that had burned at least three years before the study began. They found no significant evidence that fires permanently affected the snail community in the forest. Several factors make it difficult to apply these results directly to western forests. First of all, the burned sites were small (Strayer et al. considered them to be small, but did not give actual sizes) and within a landscape of forest from which they could be recolonized. Secondly, the deciduous component of the Maine forest is greater than the deciduous component of most western forests. In general, eastern forests are moister than western forests. Finally, it is not clear how intense the fires were in this study. Small, cool, low intensity fires may have quite different effects than the severe wildfires in the western forests.

Ruesnik (1995) studied the snail community in England's chalk grasslands. These areas are heavily managed with grazing, mowing, and some burning. In this area the variation in management strategies among sites allowed for the survival of a variety of grassland species. However, some change-over in species composition occurred at some sites. Some non-grassland species were present in the site with both burning and grazing, but the burning had occurred more than 40 years previously. Unfortunately, the set-up of this study does not allow any conclusions to be drawn specifically about burning apart from mowing.

In contrast to the effects of fire discussed above, Beetle (1997) found that fires had a major impact on snails in Yellowstone National Park. This study focused on moist aspen groves. Beetle searched for snails in burned and unburned aspen groves over a five-year period following the 1988 fires. In the year following the fires, she found fewer individual snails and fewer species in the burned areas than in the unburned areas (the article does not give specific numbers or results of any significance tests). The number of species found in the burned areas declined further in subsequent years. A severely burned grove, where all aspen litter burned, had no living snails five years after the fire. Beetle comments that aspen groves in Yellowstone are fairly isolated, which makes recolonization difficult.

Karlin (1961) found no snails in Montana coniferous forests five years after a fire, but snails were present in stands burned 23 years previously that now had pine and aspen trees. Richness and abundance of many snail species was significantly reduced on burned grassland sites in the Midwest (Nekola 2002b), but no differences were detected in *Vertigo arthuri* as explained above. The effects of fire differed among snail species, depending on their ecological preferences. In France, Kiss and Magnin (2003) found that diversity and abundance of snails decreased after fires, but the type of habitat structure influenced which species survived. For example, areas with rocks did not burn as intensely, so snails at those locations tended to survive in higher numbers. In addition, oak (*Quercus pubescens*) stands had deep litter that encouraged the presence of *Pomatias elegans*, but this snail apparently could survive the fires by burrowing deeper into the soil than other species.

Kiss et al. (2004) found that the composition of snail communities in France was not affected under low intervals of fires. They presumed that the snails are able to survive in small refuges. The overall community composition was more influenced by geography than by fire disturbance in these sites. However, in areas where regular disturbance (fire and/or other anthropogenic disturbances that altered the landscape) occurred over decades or longer, the snail community shifted to species more specialized to dry areas. No *Vertigo* species were included in this study.

A study in an agricultural area of Germany found that the number of live snails is reduced by more than 50 percent after controlled winter burning (Page et al. 2000). They also found that small snails have difficulty recolonizing burned areas. They provided several recommendations for prescribed burns. Burns should be planned for the time of year that all snails will be hibernating, which they consider to be at temperatures -10 ^{o}C (+14 ^{o}F). They also recommend fast fires to minimize the effects on snails. Lastly, they recommend a minimum burn interval of three years, but they do note that small snails may require more time to recolonize areas.

How snails recolonize areas after fires is still not clear. Presumably their refuges are critical sources. Although refuge areas are not known, they would probably include moist areas with deep litter, such as aspen areas. Unless future information suggests that *Vertigo arthuri* are able to survive low-intensity fires or are able to disperse to regularly recolonize depleted areas, extreme care should be used to minimize burning in areas where *V. arthuri* are known to reside.

Roads

Although no studies specifically address *Vertigo arthuri*, road building can negatively affect snails in a couple of ways. First, the physical process of road construction can eliminate snail habitat and/or kill snails immediately. Second, brush clearing or weed spraying along roads for maintenance could also damage snail habitat and/or snails. Several known sites are located near roads (see Frest and Johannes 2002) and are especially susceptible to these activities if their locations are not noted by road crews.

Other snail species have been shown to avoid roads (Baur and Baur 1990, Meadows 2002), which may further isolate populations. Meadows (2002) found that the road avoidance exhibited by *Oreohelix peripherica wasatchensis* was due to the absence of leaf litter, so even small paths (the smallest measured in Meadows' study was 0.7 m [2.3 feet] wide) have an effect if no litter is present. If roads are preventing movement, this may further reduce the species' ability to disperse and may make recolonization after disturbance events even more difficult.

Timber harvest

No specific data are available related to how *Vertigo* species respond to timber harvest. A sensitivity model developed for an Australian carnivorous snail, *Tasmaphena lamproides*, indicates that snail populations will remain viable longer in areas where clearcutting occurs if contiguous, unfragmented forest areas are maintained to allow dispersal (Regan et al. 2001). The relevance of this model to *V. arthuri* is unknown, because dispersal rates for *V. arthuri* are unknown and the species appears to have a naturally patchy distribution in the Black Hills (i.e., it is usually found in areas with some deciduous component rather than in the ponderosa pine that makes up the majority of the forest matrix). Also, clearcutting is not generally done in the Black Hills National Forest where the species lives. Specific data on the effects of other types of silvicultural treatments are unknown. However, it is logical that for a species that depends on microhabitat conditions, any action affecting the amount of litter, soil moisture, or temperature would negatively impact snails at that location.

Frest and Johannes (2002) did find small colonies in logged areas in conjunction with "single large logs or small piles of large wood debris" (page 65). They do not specify what type of silvicultural treatment occurred in these areas. Obviously these areas were somewhat sheltered from initial ground disturbances from the logging activity. Frest and Johannes (2002) question whether the snails will be able to survive the wider habitat changes to the stand.

In addition to the effects of the actual removal of the overstory vegetation, other aspects of logging activities could potentially affect snail habitat. For example, compaction of soil from heavy equipment could potentially crush snails. Disturbance or removal of ground vegetation, litter, decaying logs, or rocks may also reduce the cover available for the species. No studies are available that address such effects.

Grazing

Grazing can also potentially affect *Vertigo arthuri* populations if livestock crush snails directly or if their trampling changes the habitat or dries up springs or riparian areas, thereby changing the moisture regime. Fleischner (1994) reviewed many studies of the effects of grazing in riparian habitats in the western United States. Although not specifically addressing snails, the potential effects he discussed that are relevant to soil organisms near streams include increased soil compaction, increased soil temperature due to vegetation removal, removal of soil litter, and changes in vegetation composition.

Frest and Johannes (2002) indicated that *Vertigo arthuri* are generally absent from grazed areas. Individual *V. arthuri* sites likely vary in their susceptibility to the effects of grazing. Sites not within grazing allotments and extremely steep sites are not likely to be used by cattle. Sites near springs or on relatively level ground may be more susceptible to negative grazing effects.

Very few scientific studies have addressed the effects of grazing on snails. Morris (1969) found fewer snails in grasslands grazed by cattle than in ungrazed grasslands in Britain. The response was species-specific, depending on how sensitive the species was to the more xeric conditions following grazing. One species increased in abundance by one in grazed areas, two species showed equal numbers, and seven species had higher abundances in ungrazed areas—including four species, one of which was a *Vertigo* (*V. pygmaea*), found exclusively in the ungrazed areas. Ruesnik (1995) also found differences in the snail communities in grazed and ungrazed areas. Killeen (2003) reports significantly lower densities of *V. moulinsiana* in grazed areas of fens in England than in ungrazed areas.

Motorized recreation

No information is available on the effects of motorized recreation on *Vertigo arthuri*. Motorized recreation that creates new roads or bare paths will essentially create new barriers for snail dispersal, as do existing roads. (A discussion of the effects of roads is given above.) Off-road recreation could also destroy snail habitat or the snails themselves, if the activity occurs directly in the habitat area. In Montana forest habitat, off-road motorcycles were shown to have trampling effects on vegetation such as increased percent of bare ground, increased trail width and depth (Weaver and Dale 1978). Soil compaction was also demonstrated to occur from off-road vehicle use in desert shrubland soils in Nevada (Lei 2004). Direct effects of trampling on snail communities have not been studied, but could potentially include the amount of moisture in the soil.

Individual snail locations most likely vary in their susceptibility to these effects due to their geography and/or topography. Although extremely steep locations are probably the most fragile, they are probably not commonly used for motorized recreation. Moderately steep locations may be the most susceptible because they may be the most attractive for off-road vehicles, especially if tree cover is sparse.

Non-motorized recreation

No information is available on how *Vertigo arthuri* responds to non-motorized recreation. No studies have investigated the effects of non-motorized activities directly on snail populations, but some information is available that suggests some effects of such activities on soil and/or vegetation. For example, Weaver and Dale (1978) showed that horses and, to a lesser extent, hikers did cause trampling effects in forest habitat in Montana. These trampling effects included an increased amount of bare ground and increased soil compaction. These effects were more pronounced on slopes than on flat areas. Hiking and bicycling also increased soil compaction in desert shrubland habitats in Nevada (Lei 2004).

Such recreational activities could potentially destroy snail habitat or the snails themselves, if they occur directly in the habitat area. Individual snail locations most likely vary in their susceptibility to these effects based on their geography and/or topography. Extremely steep, cliff-like habitats are probably not commonly used for these types of activity, but they could be susceptible to rockfalls, which may alter the snails' habitat. Moderately steep locations may be most affected, especially if trails are nearby.

Blowdown

No information is available on how *Vertigo arthuri* respond to blowdown events. Although a falling tree could potentially have an immediate effect on a snail colony, a blowdown event would probably have a larger effect due to habitat change. A blowdown that removes most of the overhead canopy will change the temperature and moisture regimes at that location, thereby affecting the snails present. Ground cover would be initially increased, but this may not outweigh changes in overall drying conditions.

Mining

No information is available on the effects of mining on *Vertigo arthuri*. However, mining operations that removed vegetation and/or changed the soil structure of a site would likely have a negative effect.

Weed treatment

No information is available on the response of *Vertigo arthuri* to herbicide treatments. However, because the snails are in such close contact with ground vegetation and soil, it is likely that they ingest any chemicals applied to the area and may be negatively affected.

Exotic species

No information suggests that *Vertigo arthuri* interact strongly with any exotic species currently present in the Black Hills. Unless an exotic plant species outcompetes a native plant species that provides significant litter utilized by the snails or unless an exotic plant contains some toxin for the snails, it is unlikely that exotic plants would currently be a threat to this species.

Over-utilization

No information suggests that commercial, recreational, scientific, or educational purposes threaten the species.

Conservation Status of Vertigo arthuri in Region 2

More study is needed to fully understand the conservation status of *Vertigo arthuri* in USFS Region 2. Priority areas should include those areas where historical records exist and adjacent areas with similar habitats. In general, snails have not been thoroughly surveyed in much of the region, so it is unclear if current records accurately represent the range of *V. arthuri*.

The actual distribution of *Vertigo arthuri* is unlikely to increase over the entire region because of its limited dispersal ability. The recognized distribution may increase as surveys identify previously unknown locations. Distribution and abundance may be declining in localized areas of the Black Hills due to recent fire activity or other localized disturbances, but this has not been definitively proven.

Because snails have limited dispersal ability and are sensitive to temperature and moisture conditions, they are vulnerable to habitat changes. More investigation is needed on the precise microhabitat needs of the species, but deep litter with some deciduous component and/or moist rocky cliffs or boulders are apparently important for food and/or shelter. Environmental stochastic events, such as fire or trampling, can potentially eliminate local populations from an area. Recolonization is difficult because of the limited dispersal ability of snails. Current forest guidelines in the Black Hills National Forest attempt to protect areas known to be snail habitat. Some management activities such as road building, weed spraying, or timber harvesting may negatively affect local populations and care should be taken when these are conducted near snail populations. If habitat is mapped, management activities take into account the presence of snails, and the representative populations are monitored, the species is probably not at immediate risk. However, the species is probably not able to adjust if large portions of its current habitat are eliminated.

Potential Management of Vertigo arthuri in Region 2

Implications and potential conservation elements

Much of the basic biology of *Vertigo arthuri* remains unknown (see discussion above). Without detailed information on microhabitat requirements and life history, it is impossible to state the effects of management activities with certainty. The discussion here is based on the limited available information on *V. arthuri*, supplemented with information on other snail species.

Consequences of environmental change

Snails are generally susceptible to activities that change the temperature and moisture at the soil or litter level. Additional microhabitat conditions (soil type, type and amount of plant ground cover, soil pH, depth and type of litter, amount of cover from rocks or woody debris) also play a role in where the snails can survive. Therefore, activities that significantly change these factors in the snails' environment are likely to affect the abundance and/or distribution of the species. However, specific tolerances of *Vertigo arthuri* are unknown, so it is only possible to discuss theoretical effects.

Management activities, such as timber harvesting, that remove canopy cover can increase soil temperature and reduce moisture levels. This can cause snails to dry out and possibly die; a major cause of death for snails is desiccation (Solem 1984). Even timber harvesting near a snail colony could potentially lower existing moisture levels at the colony site, so a buffer area is probably required. The amount of litter or other cover, elevation, aspect, etc. may also affect the soil temperature, and therefore the width of a buffer needed may vary among sites. Data on how small of a temperature or moisture change affects *Vertigo arthuri* and how wide of a buffer area is necessary are not available, but these questions should be investigated.

Activities that change the amount of ground vegetation and/or litter directly, such as fire, grazing, and understory management practices, can eliminate food and/or cover for the snails. While snails may be at immediate risk from these practices through trampling or burning, these changes may also make the habitat unsuitable at least for the short term, and possibly for longer time periods if substantial changes are made. Data on how much litter and what species of ground cover are required by *Vertigo arthuri* are not available, but should be investigated.

Page et al. (2000) provide several recommendations for prescribed burns. Burns should be planned for the time of year that all snails will be hibernating, which they consider to be at temperatures -10 ^{o}C (+14 ^{o}F). They also recommend fast traveling fires to minimize effects on snails. Lastly, they recommend a minimum burn interval of three years, although they note that small snails may require more time to recolonize areas. Killeen (2003) suggests that although many fires are likely detrimental to snails, rapidly moving spring fires that do not destroy vegetation's roots have not affected populations of *Vertigo moulinsiana*.

Activities that fundamentally change the structure of the talus or cliffs, such as road building or other development, severe instances of off-road motorized recreation, mining, or gravel quarrying, can eliminate shelter for the snails. This may lead to increased exposure to predators or increased risk of desiccation. Activities that damage springs or otherwise change the moisture regime at a site can affect the amount of soil moisture available to the snails. This may affect the population size or distribution of a colony.

Chemicals applied to an area, such as herbicides or fire retardants, may be ingested by snails. If chemicals cannot be avoided, Burke (1999) recommends that they be applied during dry periods, when snails are less likely to be active at the surface.

Desired environmental conditions

Specific tolerances of *Vertigo arthuri* are currently unknown, so this discussion represents a conservative understanding of desired conditions. The desired conditions should be revised as more information becomes available. Conditions differ among individual snail colonies, so management strategies must be evaluated on a colony to colony basis, until such time as general tolerances are understood. The most conservative management approach would attempt to keep the current conditions at each location with regards to talus structure, moisture regime, vegetation species composition, canopy cover, and amount of ground cover. These conditions should be maintained as long as populations are relatively stable. Should a downward trend be noted, other management approaches may need to be invoked to establish conditions more similar to sites where populations are stable.

Strategies to conservatively manage snails could include: 1) eliminating any management activities within the boundaries of the known snail colonies, 2) fencing colonies or restricting activities in areas where motorized off-road recreation is common, and 3) educating the public on low impact recreation practices. Buffer areas around known snail colonies should be of sufficient width so management activities nearby do not change the temperature and moisture levels at the snail colony. Because many colonies are located on steep locations where management activities and recreation do not normally occur, no action is probably required for such sites. Less conservative management strategies, for example eliminating the need for fences, could be sufficient if monitoring or other studies showed activities were having no effect on the snails or their habitat. Eliminating all disturbances at all colonies will not be possible since some activities are not under the control of managers (i.e., wildfire). In such cases where disturbance does occur, the snail population should be monitored, and if necessary, restoration approaches should be developed.

Successful methods for restoration of habitat for terrestrial snails have not been thoroughly developed. In cases where restoration of habitat is necessary because individual snail colonies are decreasing, care must be taken to not further disturb the underlying structure of the site while attempting to improve it. Increasing the deciduous trees and/or shrubs in order to increase the deciduous litter component at sites with declining populations may be helpful. Repairing damaged mosses or reforesting areas to increase canopy cover may also be helpful. However, without further information on specific microclimate preferences, it is impossible to recommend specific amounts of material needed for habitat restoration.

Tools and practices

Vertigo arthuri has not been extensively studied. However, methods used for studying other snail species are generally applicable to *V. arthuri*, and these are discussed here.

Inventory and monitoring

Inventory and monitoring involves four separate aspects: 1) species inventory, 2) habitat inventory, 3) population monitoring, and 4) habitat monitoring. Each of these will be addressed separately.

Species inventory involves general surveys to determine the distribution (presence/ absence) of the species. Species inventories are commonly done by either hand-searching the vegetation and litter for snails or by collecting litter/soil samples and sifting through them at a later time. Sampling has also been done using cardboard cover boards as "traps" (Hawkins et al. 1998). Emberton et al. (1996) suggest that a combination of soil/litter sampling and timed hand-searching is most efficient when interested in a wide range of snail species. Soil/litter sampling has the advantage of including empty shells in the sample, so rare species have a higher chance of being found. An alternate survey method, sometimes used in dry environments, involves wetting down an area with water and observing snails that surface (Grimm personal communication 2003).

The Bureau of Land Management in Oregon has developed a protocol to survey for terrestrial mollusks (U.S. Bureau of Land Management 1998). Their Terrestrial Mollusk Survey Protocol could be applied to areas in Region 2 to determine what areas support *Vertigo arthuri* or other snail species. This protocol includes standardized hand-searches for a variety of snail species.

Habitat inventory involves surveying to determine whether appropriate habitat is available for the species. This assumes that the exact habitat requirements for the species are known. Because the known habitat requirements for *Vertigo arthuri* are somewhat general, it may be necessary to conduct a snail survey at the location to determine if the habitat is actually suitable for the species. Specific microhabitat characteristics important for *V. arthuri* might include specific soil moisture levels, pH, calcium levels, soil type, plant or fungi species, etc. Once the specific requirements are identified for the species, habitat inventory becomes much more reliable. Source versus sink areas for the species could potentially be identified through such habitat inventories. However, with a patchily distributed species like *V. arthuri*, source habitat becomes somewhat speculative since populations will not be present in all possible habitats.

Population monitoring that actually evaluates the size of the population requires a sampling method that can provide a statistical estimate relating the size of the sample to a known area. Three basic methods exist to sample snails in order to obtain population estimates: soil/litter sampling, mark-recapture, and trapping with cardboard (or wood) boards. The strengths and weaknesses of these three methods were evaluated by Oggier et al. (1998) in Swiss grasslands. Soil sampling that consists of removing and searching soil from stratified random locations has been well-supported (Bishop 1977) because it avoids biases. Litter sampling at established grids was used to monitor *Vertigo angustior* in Europe (Fowles 1998). However, Oggier et al. (1998) point out that soil sampling is extremely time consuming and is destructive to both the habitat and the animals, since snails are removed to the laboratory for identification. The actual amount of soil and/or litter sampled varies among studies, and the efficiency of different strategies can be impacted by the time of year and the species in question (Kuznik 1997). *Vertigo moulinsiana*, which reside in marsh habitat in England, have been monitored by beating vegetation and collecting snails that fell to a sheet on the ground (Stebbings and Killeen 1998). However, since *V. arthuri* is usually in the litter, this type of sampling method would not be effective. Emberton et al. (1996) suggest a combination of soil/litter sampling and timed hand-searching is the most efficient method when interested in a wide range of snail species.

Mark-recapture methods consist of hand-searching vegetation and litter across a grid and marking the individuals observed. Repeated visits to the grid provide data that can be used for statistical estimates of population size. Some handling of the snails is usually necessary, unless the snails are large and remain visible when inactive (Schilthuizen and Lombaerts 1994); this is not likely to be the case for *Vertigo arthuri*. Oggier et al. (1998) found that this method was less time intensive and caused less disturbance to the snails and the habitat than soil/litter sampling. They were able to alleviate some trampling disturbance by elevating a walkway over their grid. However, mark-recapture methods are difficult with the smallest species or with species that cannot be identified in the field, such as *V. arthuri*. With *V. arthuri* it may prove necessary to identify individuals with a field microscope before marking and returning them to the grid. This step may make these methods impractical. Mark-recapture methods are also somewhat weather-dependent.

Traps consisting of corrugated cardboard or wooden cover boards have also been used (Boag 1982, Hawkins 1998). Oggier et al. (1998) found that the cover board method has the least time commitment and causes the least disturbance, but it depends on weather. Boag (1982) watered areas under the boards in dry areas in order to increase captures. Some snail species may respond differently to the traps than others (Boag 1982). Nevertheless, Oggier et al. (1998) considered cardboard sampling boards to be the best method for large areas. Boag (1982) also points out that cover boards provide a better picture of what life stages make up the current population than either hand searching, which may not pick up all life stages equally, or soil sampling, which includes dead shells. Cover boards have not been tested with any *Vertigo* species and may not be practical for such a small species, but a discussion of the methods are included here to encourage experimentation with the method.

Populations can also be monitored using a combination of boards and mark-recapture methods. In Iowa, a federally endangered snail has been monitored by setting up a grid in its habitat and conducting mark-recapture studies (Ostlie 1991, Anderson 2000, Henry et al. 2003). Marking would allow biologists to estimate population size and to monitor population trends. There are several potential difficulties with this approach. First, someone who can identify the snail species in question is required in the field. This is especially true for *Vertigo arthuri* because other *Vertigo* species are present in the area and it is difficult to distinguish among them without a microscope. A second difficulty is that with small snails like *V. arthuri*, snails are not easily marked with fingernail polish or bee tags. Third, this approach is time intensive because repeated visits must be made to a site to record recaptures. Because of such time requirements, monitoring populations across an entire forest may not be practical. However, representative populations could be monitored with less effort. A fourth difficulty is that baseline information on the variability in the *V. arthuri* populations over time is not available. Without this information, it is difficult to determine ideal time periods for monitoring, and it is virtually impossible to interpret trends. However, as information is gathered, trends will eventually emerge.

Monitoring habitat is a possible alternative to detailed population estimates. Habitat monitoring must be conducted at each population location because the snails are tied to a specific location. The overall habitat quality in a forest or even a stand may or may not apply to the specific spot where the snails reside. Important elements to include in habitat monitoring would be a visual, on-the-ground inspection of the area to determine if the integrity of the habitat had changed. For example, on a steep site did an avalanche occur that may have crushed snails or removed part of the habitat? Was a fire intense enough to remove important vegetation? Perhaps certain habitat characteristics could be monitored, such as depth of litter layer, presence of deciduous trees, soil temperature, etc.

Population and habitat management approaches

Management options for snails range from hands-off to monitoring to intensive hands-on relocation/reintroduction approaches. The current management strategy in the Black Hills National Forest is basically a hands-off approach whereby known snail colonies are avoided during management activities that might potentially disturb snails. Protecting known and potential snail habitat is essential to maintaining populations of the species.

The USFS recommendations for preserving an undescribed arboreal *Vertigo* species, the Hoko *Vertigo* in Washington, also includes avoiding management activities such as fire, chemical applications, or recreation activities directly on the snail habitat areas (Applegarth 1999). Setting aside preserves for snail species of concern has also been practiced in Europe (Alexander 1998). This approach is the least time-intensive. One drawback is that it does not provide information on the health of the population at the forest-wide level since no monitoring is done. Combining reserve areas with monitoring has been the strategy for some snail species in Europe (Drake 1998) and Iowa (Henry et al. 2003).

Henry et al. (2003) developed a monitoring protocol for *Discus macclintocki*, a land snail in Iowa. This protocol uses cover boards and mark-recapture methods to track a subset of populations. Sampling data collected each year, together with environmental information such as temperature and moisture levels, are allowing managers to begin to detect trends in the populations. This approach can be somewhat intrusive on fragile habitat, and Henry et al. are considering longer intervals between sampling. This approach is much more time-intensive than a hands-off approach because repeated visits are needed at each site for marking and recapturing individuals. However, it does have the advantage of providing data on the status of the species, at least at the sites included for monitoring. For a species like *Vertigo arthuri*, which is extremely small and difficult to identify, this approach may not be practical.

Captive breeding and relocation/reintroduction programs have been developed for some critically imperiled snail species. One such program is described in Mace et al. (1998) where Polynesian tree snails (Family Partulidae) became imperiled when an exotic carnivorous snail was introduced. Zoos around the world are collaborating to maintain captive colonies of these species until they can be reintroduced to areas where the carnivorous snail has been eradicated. The program involves raising the animals in captivity, managing a breeding program to maintain genetic diversity, and hopefully releasing the snails back into the wild. Obviously, this approach is extremely expensive and time-intensive. It also requires detailed knowledge of the species' nutritional and habitat requirements in order to successfully raise them in captivity. Even then, the animals may be susceptible to disease or the loss of behaviors necessary to survive in the wild, so it should only be considered as a last resort.

An alternative strategy for preserving snails and their habitat occurred in England when *Vertigo moulinsiana*, a rare marsh snail, was found in an area undergoing road development (Stebbings and Killeen 1998). In this case, a new marsh was constructed by moving the turf and the resident snails to another suitable area. Early results showed that breeding continued in the new area, suggesting the snails may become established there. Again, this method is expensive and is not suitable for habitat types that cannot be reconstructed. For *V. arthuri* in Region 2, reconstructing habitat and reintroducing snails is not practical unless much more information becomes available on the specific microhabitat needs of the species.

Information Needs

The distribution of *Vertigo arthuri* in Region 2 is known only from the Black Hills region of western South Dakota and eastern Wyoming. Because much of its known range has been only recently discovered, additional surveys in the region may uncover more locations.

The response of *Vertigo arthuri* to changes in habitat is not well understood. Information on how they recolonize areas after fires and how timber thinning treatments affect the litter layer is essential in order to understand how management affects the species. Understanding the species' sensitivity to temperature and moisture changes and the relationship of these factors to timber harvesting, grazing, and road building would allow better planning of buffers and mitigation measures.

Although information on general habitat is known, preferred microhabitat is still somewhat undefined, as is information on foraging and shelter needs. Information on predators in the region is virtually non-existent.

The relationship between this species and other *Vertigo* species is not well understood either in Region 2 or elsewhere in its range. A better understanding of the taxonomy would also allow an understanding of whether any hybridization occurs.

Temporal population patterns are not well understood. This information is important for establishing proper times for monitoring as well as for suggesting times to avoid disturbance, such as the breeding period. Dispersal patterns are unknown for *Vertigo arthuri*. Understanding dispersal would provide insight into how connected (or isolated) populations are, as well as provide understanding as to how disturbed areas might be recolonized.

Our knowledge of the demography of *Vertigo arthuri* is extremely limited. Because reproduction rates, survival rates, and dispersal rates are unknown, it is impossible to analyze persistence at the local and/or regional scales.

Although they are not currently being utilized, methods are available to monitor population trends. Population estimates can be determined from monitoring studies, as discussed above. Trends can be determined as data are gathered over several years.

Restoration methods for *Vertigo arthuri* habitat are not readily available. Because information is lacking on microhabitat needs, it is difficult to envision being able to currently restore damaged habitat with high success. In addition, without relocating snails to the restored habitat, it is difficult to envision recolonization from distant populations, unless new information on dispersal patterns surfaces.

The recommended research questions, from high to low priority, for *Vertigo arthuri* in Region 2 are as follows:

- ❖ How large are the populations, and are they stable, increasing, or decreasing?
- ❖ How do the snails respond to disturbances, such as fire, grazing, and timber harvest?

- ❖ What are the microhabitat needs of this species?
- ❖ What are the taxonomic relationships between this species and other *Vertigo* spp.?
- ❖ What are the seasonal activity patterns, and how do they relate to environmental variables?
- ❖ What are the movement patterns?
- ❖ What are the demographic rates for this species?
- ❖ How much of a factor is predation for this species?
- ❖ How much do these snails compete with other snail species?

Strategy, priority, and costs for each information need are listed in **Table 1**. High priority items are essential for short-term protection of the species. Medium priority items are probably necessary for longer-term management of the species. Low priority items would help in management but are not critical. Monetary costs are estimated on a per year basis. Costs are evaluated for each topic individually. If several topics were combined and addressed by the same strategy, the total costs would be decreased.

Table 1. Research priorities for *Vertigo arthuri* in USDA Forest Service Region 2.

Information Need	Recommended Strategy	Priority Level	Estimated Cost and Time Investment
How large are the populations and are they stable, increasing, or decreasing?	Monitoring study using cover boards at multiple populations	High	$10 to 15,000 first year, $5 to 6,000 subsequent years; multiple year study
How do the snails respond to disturbances such as fire, grazing, and timber harvest?	Experimental study and/or observations after disturbances; could partially be addressed (at lower cost) with models if demographic data were available	High	$20 to 30,000 per year; multiple year study
What are the microhabitat needs of this species? (understory, soil, litter requirements, etc.)	Observational study	High	$5 to 10,000 per year; one- to two-year study
What are the taxonomic relationships between this species and other *Vertigo* species?	Molecular and anatomical study	Moderate	$40 to 50,000 study
What are the seasonal activity patterns and how do they relate to environmental variables?	Observational study	Moderate	$5 to 15,000 per year; one- to two-year study
What are the movement patterns? (daily movement and dispersal)	Mark-recapture study, or possibly pit tags	Moderate	$15 to 20,000 per year; multiple year study required
What are the demographic rates for this species? (survival, reproductive rates, etc.)	Mark-recapture and/or observational study; could be combined with lab rearing study	Moderate	$15 to 20,000 per year; multiple year study required (data could allow modeling of response to habitat change)
How much of a factor is predation for this species?	Observational study	Low	$2 to 5,000 per year; multiple year study
How much do these snails compete with other snail species?	Experimental and/or observational study	Low	$5 to 10,000 per year; multiple year study

DEFINITIONS

Note: The following definitions reflect biological and morphological aspects of *Vertigo arthuri*. A generic shell diagram illustrating shell morphology terms is found in **Figure 8**.

Aestivation — a resting state into which snails enter when conditions are not favorable, such as when temperatures are too high or moisture levels are too low.

Aperture — the opening in the shell leading into the shell itself; the snail body extends from this opening.

Aphallic — individuals that lack penal structures and serve as females when mating; they may still have organs to produce sperm (i.e. vas deferens) and may self-fertilize.

Basal fold — a tooth-like projection on the lower lip.

Callus — a thickening of the shell.

Columellar lamella — a tooth along the inside lip.

Cover-board — a wooden or cardboard sheet placed on the ground in one method of counting snails; the snails use the board for shelter and often remain attached to the board or at the surface underneath so they can easily be seen and counted.

Desiccation — drying out.

Euphallic — individuals that contain complete reproductive structures and usually serve as males when mating with other individuals; also capable of self-fertilization.

Gastropod — a group of mollusks that includes snails and slugs.

Hermaphrodites — contain both male and female reproductive organs.

Lamellae — teeth projecting from the upper or inner lips.

Microhabitat — characteristics of the immediate environment of the population.

Palatal folds — tooth-like projections on the outer lip.

Peristome — surrounds the aperture; also called the lip.

Pulmonate — a snail that uses lungs to obtain oxygen.

Radula — rows of teeth used to scrape food particles off a surface; found in all mollusks.

Ribs — raised lines on a snail shell that are perpendicular to the direction of the whorls.

Teeth — projections of the shell within the aperture (not to be confused with teeth on the radula); include lamella, etc.

Umbilicus — the opening on the underside of some snail species' shells, depending on the shape and coiling pattern of the shell.

(a)

(b)

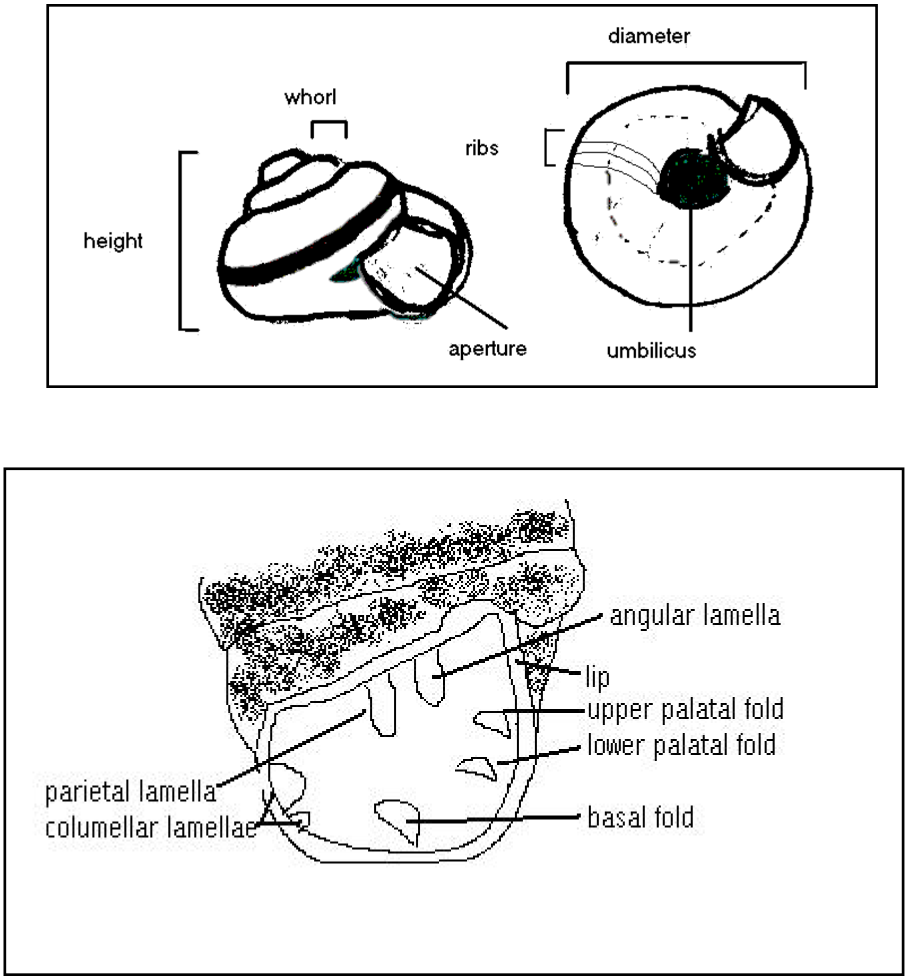


Figure 8. Diagram illustrating shell morphology of snails. The shells shown here are not meant to represent *Vertigo arthuri* but are generic shells. Diagram (a) shows general shell parts, and diagram (b) is a close-up of the aperture illustrating the names of teeth.

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